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AN EXPERIMENT TO STUDY THE NUCLEAR
COMPONENT OF PRIMARY COSMIC RAYS

TECH - 29

J.M. Paul and S.D. Verma

Department of Physics and Astronomy,
Louisiana State University,
Baton Rouge, Louisiana 70803 USA

An apparatus has been designed and is being fabricated to study the charge composition, fluxes, and energy spectra of light nuclei ($Z \leq 8$) in the energy region from 1 GeV to 100 GeV. The apparatus essentially consists of an array of a large number of particle detectors operated in coincidence and serving as a charged particle telescope. A mosaic silicon semiconductor detector, a plastic scintillation counter and a lucite cerenkov detector are used to measure the charges of the incident nuclei. Two one-inch thick CsI(Tl) detectors are used to study low energy particles. An ionization spectrometer is utilized to measure primary energies in the 1 to 100 GeV energy interval. The spectrometer consists of alternating layers of tungsten absorber and plastic scintillator. A gas cerenkov counter is being designed to distinguish between electrons and protons. It is planned to calibrate the apparatus at an accelerator using particles of known energy. The apparatus will be exposed at high altitudes using balloons launched from Palestine, Texas. Since the geomagnetic cutoff at Palestine is about 4.5 GV, only primary particles of higher rigidities will be studied. In the same experiment, re-entrant charged albedo particles will also be studied.

1. Introduction. Primary cosmic rays have been studied in experiments flown using balloons and satellites for quite some time. In the last decade, accurate data have been obtained from a large number of satellite experiments in the 1 to several 100 MeV/nucleon energy interval. Above 100 MeV/nucleon, experiments performed at balloon altitudes are still useful for primary cosmic ray studies. We have designed an experiment (Paul and Verma, 1970) to study the primary cosmic rays in the 100 MeV to 100 GV energy interval. Plans are eventually to fly the apparatus at high altitudes using balloons launched from Ft. Churchill, Canada, in an attempt to measure the fluxes and the energy spectra of the primary cosmic ray nuclei having charges from one to eight. Possibly the electron flux and energy spectrum can be measured as well. The apparatus will first be flown from Palestine, Texas, geomagnetic cutoff about 4.5 GV, to study-reentrant charged albedo particles (Verma 1967, Israel, 1969). The apparatus has been designed, and is being fabricated and tested. It is hoped that the apparatus will be ready for balloon flights in the spring of 1972.

2. The Experiment. The experimental apparatus is essentially a charged particle telescope as shown in Fig. 1a. The detector P_1 is a dome-shaped mosaic of lithium drifted silicon detectors each 1 mm thick. Below this are a lucite Cerenkov detector P_2 and a plastic scintillation counter D_1 . Each of these

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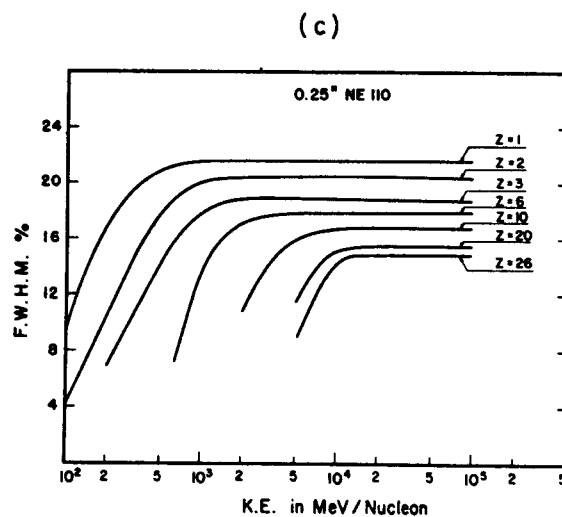
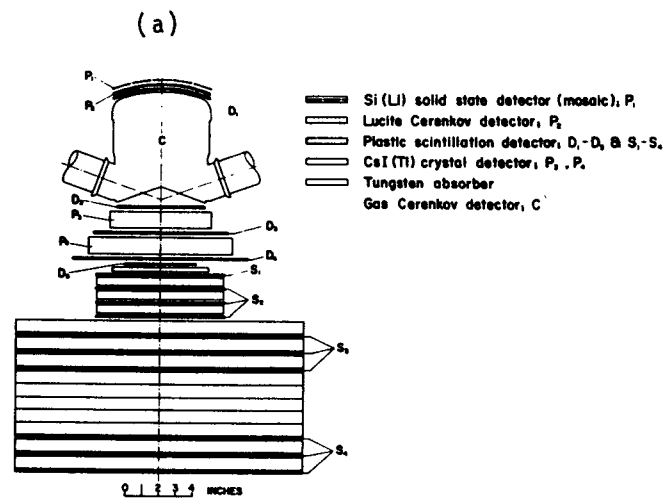
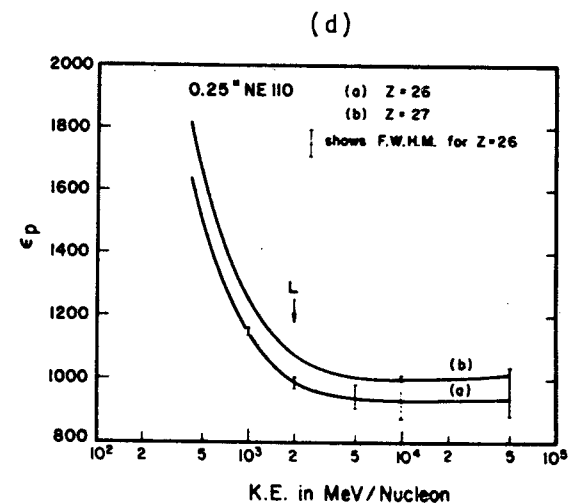
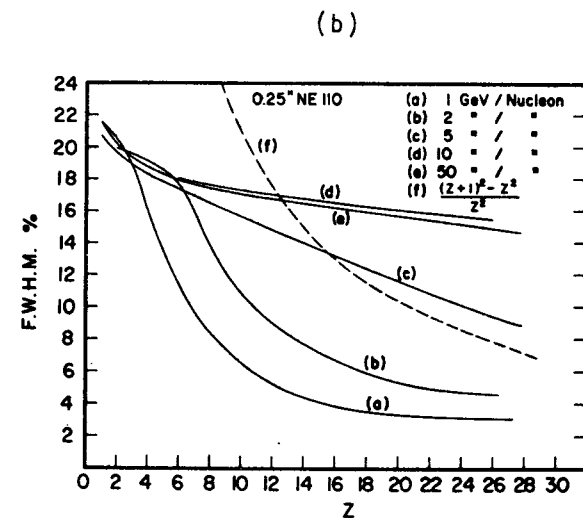


Fig. 1



detectors is $1/4$ in thick. Several $1/8$ in. thick plastic scintillation counters (D_2, D_3, D_4, D_5) are operated in coincidence with D_1 to select and define the ranges of the charged particles. Counters D_1, D_2 and D_1, D_2, D_5 define the respective geometrical factors for the low energy and high energy parts of the experiment. These geometrical factors are about $50 \text{ cm}^2 \text{ sr}$ and $25 \text{ cm}^2 \text{ sr}$, respectively. Two large CsI(Tl) crystal detectors P_3 and P_4 are placed between counters $D_2 - D_3$ and $D_3 - D_4$. These measure the total energy of the charged particles which stop within the crystals.

The energy loss (dE/dx) in D_1 and P_1 , the Cerenkov radiation produced in P_2 , and total energy (E) deposited in P_3 and P_4 are pulse height analysed. These measurements determine the charges, masses, and energies of the particles in the 50 to 300 MeV/nucleon energy interval. This assembly of detectors also measures the charges of the particles having higher energies which penetrate the assembly. These higher energy particles deposit their energies by producing nuclear-electromagnetic cascades in the ionization spectrometer which is placed below. The spectrometer consists of ten layers of plastic scintillation detectors, each viewed by single photomultiplier, sandwiched between layers of tungsten (W). Four pulse height analysers, S_1-S_4 , are used to measure the energy of the cascade produced in the spectrometer by an incident particle. A gas Cerenkov counter C, is being designed to identify electrons.

3. Performance of the Detectors. To evaluate the performance of the silicon, plastic, and CsI(Tl) detectors used in the experiment, thorough investigations have been made concerning the rate of the energy loss in the detector materials. These calculations took into account the shell correction and the density effect (Paul 1971). These results are based on the Landua (1944), Vavilov (1957) theories giving energy loss probability distributions, and on the data given by Sternheimer (1967, 69) to calculate the density effect term for Si and CsI. These have been utilized along with the general expression of Barkas and Berger (1964) for the shell correction term for various media.

3.1. Plastic Scintillation Detectors. The intrinsic resolution of a $1/4$ in plastic scintillation detector plotted as function of atomic number for energies of 1, 2, 5, 10 and 50 GeV/nucleon is shown in Fig. 1b. The dashed curve shows approximately the resolution necessary to identify two nuclei with adjacent charges. Similar curves for resolution of nuclei having charges $Z = 1, 2, 3, 6, 10$ and 26, and with energies in the range 10^2-10^5 MeV/nucleon are shown in Fig. 1c. In Fig. 1d, the energy loss ϵ_p as a function of kinetic energy is shown for Fe and Co nuclei. It appears that these nuclei with $Z = 26$ and 27 can be resolved up to about 2 GeV/nucleon.

3.2. Silicon Detector. Figure 2a shows the intrinsic resolution obtainable with a 1 mm thick silicon detector for nuclei of charges $Z = 1, 2, 3, 6, 10, 20$ and 26 in the energy interval 10^2-10^5 MeV/nucleon. Figure 2b shows this resolution as function of atomic number for kinetic energies of 1, 3, 5, 10

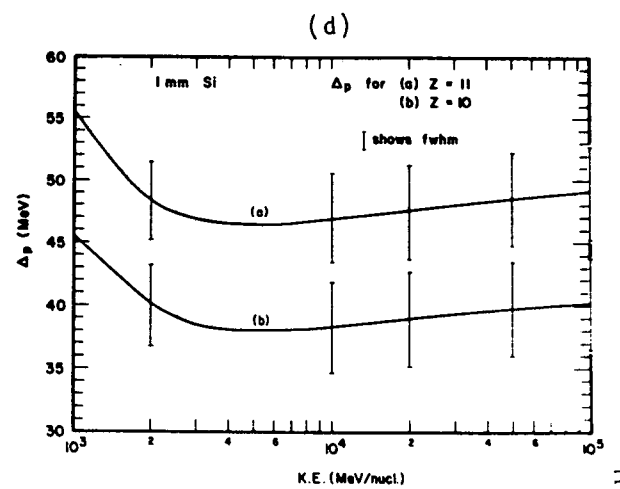
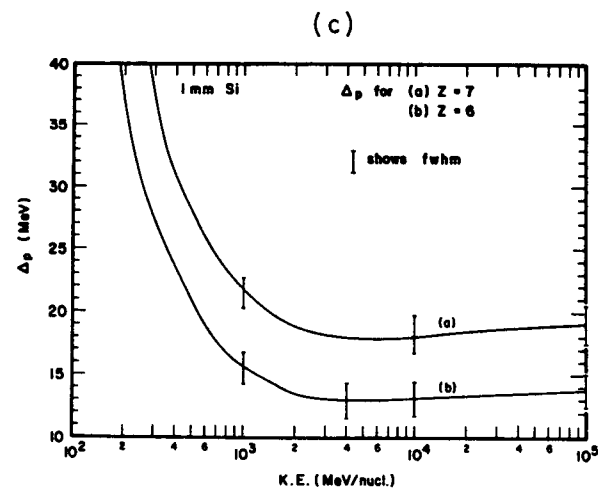
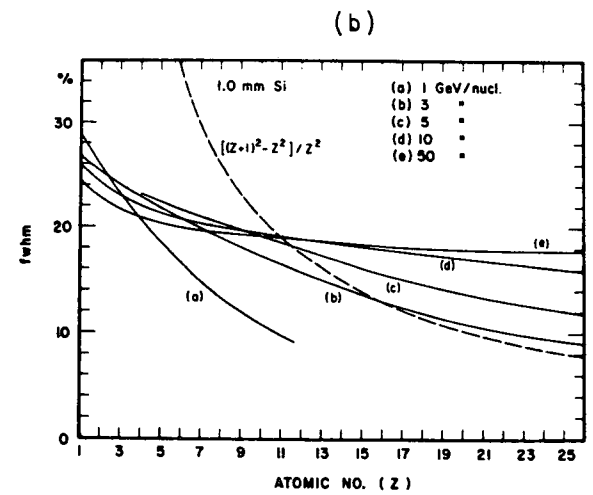
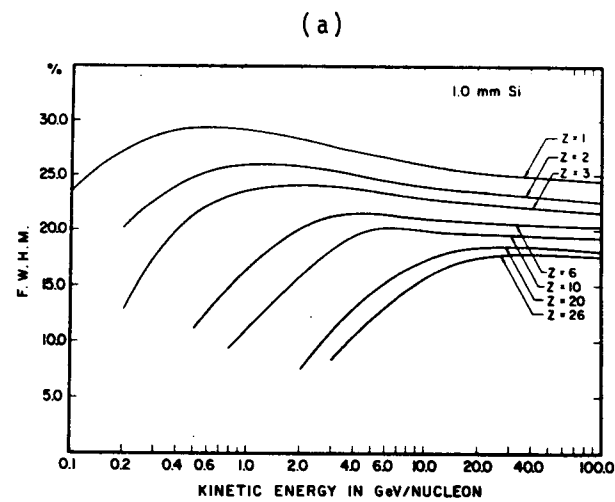


Fig. 2

and 50 GeV/nucleon. The dashed curve, $[(Z+1)^2 - Z^2]/Z^2$, shows approximately the limiting resolution necessary to identify two nuclei differing by one unit of charge. It appears that the intrinsic resolution over the whole energy range under consideration is sufficiently good to resolve the various nuclei up to about $Z = 10$. This fact has been explicitly shown in Figs. 2c and 2d, where the most probable energy loss Δp has been plotted as a function of kinetic energy per nucleon. The bars show full width at half maximum (fwhm) at various energies.

3.3. CsI(Tl) Detector. Figure 3a shows the intrinsic resolution of a one inch thick CsI detector for muons, pions, kaons and nuclei with charges $Z = 1, 2, 3, 6, 10, 20$ and 26 . Figure 3b shows the intrinsic resolution as a function of charge for nuclei having various kinetic energies. Two CsI-detectors will be utilized as energy loss detectors for very high energy particles. The dashed curve shows approximately the resolution necessary to identify two nuclei separated by one charge unit. Some results for specific cases are shown in detail in Fig. 3c and Fig. 3d. It appears that nuclei of Ne could in principle be separated from Na nuclei at all energies. However, such a separation is possible only up to about 30 GeV/nucleon for Fe and Co nuclei.

It should be pointed out that the figures for intrinsic resolution do not in any way imply a limiting resolution. In the case of scintillation detectors, this limiting resolution will be affected by light conversion and collection efficiency, photomultiplier quantum conversion efficiency, noise, etc. Similarly, in the case of silicon detectors it will depend upon leakage current, energy needed per electron-hole pair, charge integration, etc. However, the above figures give best possible resolutions.

4. Summary. To summarize, the apparatus described here will be capable of resolving cosmic ray nuclei from H to Na at all energies. Nuclei between Mg and Ni would be resolved up to approximately 3 GeV/nucleon, beyond which only alternate charges would be resolved. We will obtain only rough energy measurements in the 1 - 100 GeV/nucleon energy region, and will be able to resolve individual primary cosmic ray nuclei only up to Na. Any information on electrons would be obtained as a by-product.

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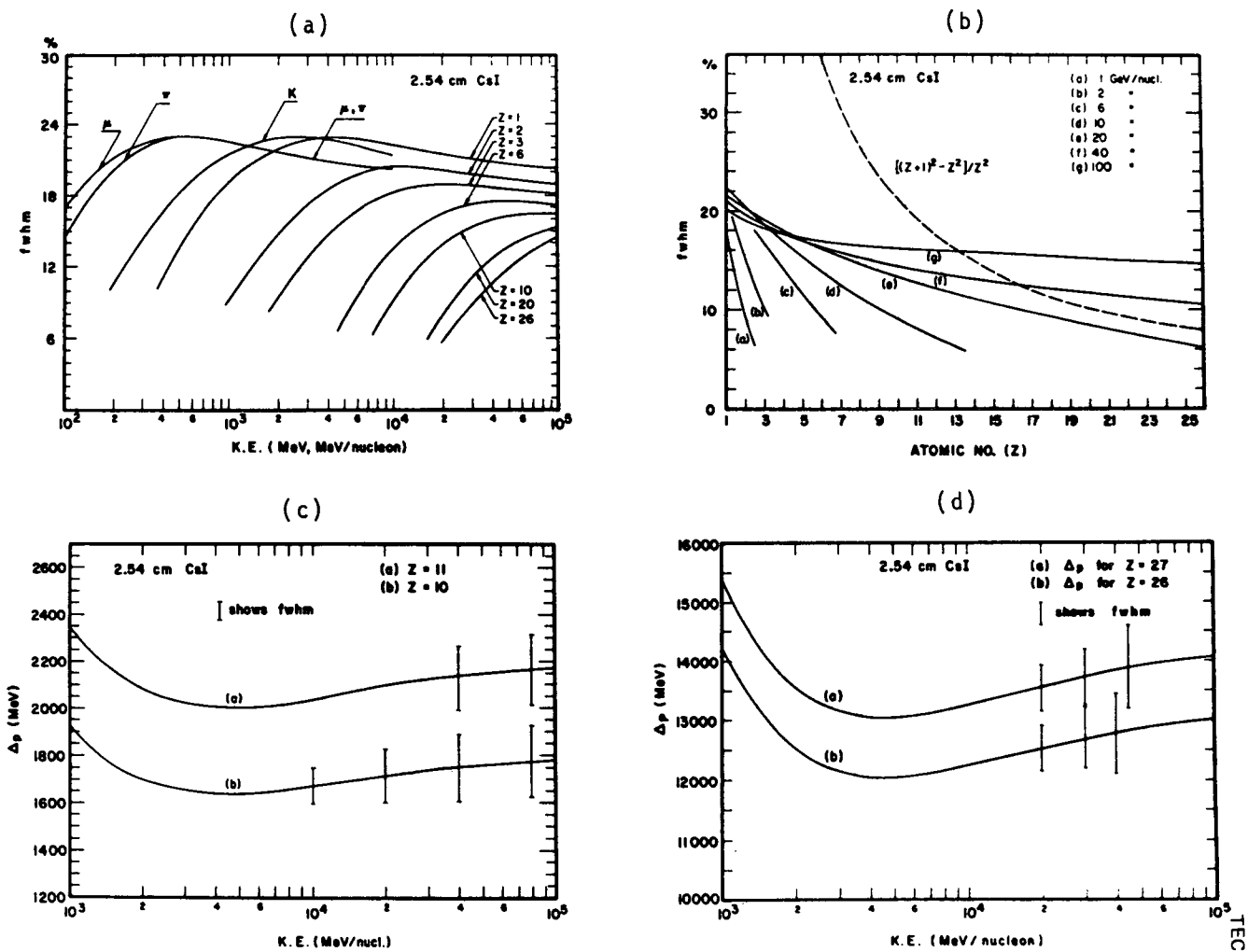


Fig. 3